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TELEX 5-29453 VOPAT D

Our ref: M 162

Case: 6092-1D

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"Apparatus for capacitive strain measurement"

Patent Claims

1. Apparatus for capacitive deformation measurement, characterized by at least two mounting boards (10, 12, 14), which each bound a gap between them, two capacitor plates (22, 24, 22', 24') which can be energized and are arranged on the

surface of a mounting board (12) bounding the gap, a capacitor measurement plate (28, 28′) which is arranged on the surface of the other mounting board (10, 14) bounding the gap and parallel to the capacitor plates (22, 24, 22′, 24′) which can be energized, and a shutter arrangement (32, 34, 32′, 34′) between the capacitor plates (22, 24 and 22′, 24′) and the respective capacitor measurement plate (28 or 28′) in order to vary the difference between the capacitances between the capacitor plates (22, 24 or 22′, 24′) and the capacitor plate (28 or 28′) respectively as a function of a change in the shutter setting.

2. Apparatus according to Claim 1, characterized in that the shutter arrangement (2) has shutter plates (32, 34, 32′, 34′) which each have at least one aperture (32a) or (34a), in that the apertures (32a) in one shutter plate (32, 32′) overlap the apertures (34a) in the other shutter plate (34, 34′) in order in this way to form capacitor gaps (C1, C2) whose size can be varied with the movement of the shutter plates (32, 34 or 32′, 34′) relative to one another, in that the shutter plates (32, 34, 32′, 34′) project on opposite sides from the gap and in that coupling means (33, 35, 33′) are provided in order to connect those sections of the shutter plates (32, 34, 32′, 34′) which project from the gap to the measurement surface on

which deformation is intended to be measured.

3. Apparatus according to Claim 2, characterized in that the coupling means have a pair of spacing elements (33, 35, 33') whose thickness corresponds to the distance between the measurement surface and those respective sections of the shutter plates (32, 34, 32', 34') which project outwards.

4. Apparatus according to one of Claims 1 to 3, characterized in that the capacitor plates (22, 24, 22', 24') which can be energized have a plurality of elongated finger-like projections which are arranged parallel and at a distance from one another, with the projections on one capacitor plate (22, 22') each being located between the projections on the other capacitor plate (24, 24').

5. Apparatus according to one of Claims 1 to 4, characterized in that the apparatus has an oscillator device (60) in order to apply alternating-current carrier signals to the capacitor plates (22, 24, 22', 24') which can be energized, with the carrier signal which is applied to one of the capacitor plates (22, 22' or 24, 24') which can be energized being phase-shifted through 180° with respect to the carrier signal which is applied to the other active capacitor

plate (24, 24′ or 22, 22′), and that a phase-sensitive detector (165) is provided for measurement of the magnitude and phase of the signals which are coupled to the capacitor measurement plate (28, 28′) through the shutter arrangement.

6. Apparatus according to Claim 1, characterized in that three mounting boards (10, 12, 14) are provided, stacked in layers one above the other, and two of which define a gap between them, in that at least one element which varies the capacitance, is arranged so that it can be moved and projects out of the gap is arranged in each gap, in that one of the deformation gauges (16, 16′) which is formed in each case between two mounting boards (10, 12 or 12, 14) is arranged rotated through a predetermined angle with respect to the other deformation gauge (16′, 16), and in that coupling means (33, 35, 33′) are provided in order to connect those sections which project outwards of the elements which vary the capacitance to the measurement surface on which deformation is intended to be measured.

7. Apparatus according to Claim 6, characterized in that the predetermined angle is about 90°, as a result of which the measurement axes of the two deformation gauges (16, 16′) run orthogonally with respect to one another.

8. Apparatus according to Claim 6 or 7, characterized in that the connecting means have a plurality of spacing elements (33, 35, 33'), whose thickness corresponds to the distance between the respective sections, which project outwards, of the elements (32, 34, 32', 34') which vary the capacitance, and the measurement surface.

9. Apparatus according to one of Claims 6 to 8, characterized in that the two deformation gauges (16, 16') each have at least one capacitor plate (22, 24, 22', 24') which can be energized on the surface of a mounting board (12) which bounds the gap and a capacitor measurement plate (28, 28'), which is arranged parallel to the capacitor plate (22, 22', 24, 24'), on that surface of the upper mounting board (10, 14) which points towards the gap, with the element (32, 34, 32,' 34') which varies the capacitance being located between the capacitor plate (22, 24, 22', 24') and the capacitor measurement plate (28, 28').

10. Apparatus according to Claim 9, characterized in that an oscillator device (60) for production of an alternating-current carrier signal is connected to each of the capacitor plates (22, 22', 24, 24') which can be energized, and in that

a detector (165) is provided in order to record the alternating-current carrier signals which are coupled to the capacitor measurement plates (28, 28′) through the corresponding elements (32, 34, 32′, 34′) which vary the capacitance.

11. Apparatus according to one of Claims 5 to 10, characterized in that the detector apparatus has a charge amplifier (62) which is connected to the capacitor measurement plate (28), and in that a feedback loop which couples the output and the input of the charge amplifier (62) to one another is provided in order to produce a virtual earth potential at the amplifier input.

12. Apparatus according to Claim 11, characterized in that the feedback loop has a capacitor (66).

13. Apparatus according to Claim 11 or 12, characterized in that the apparatus has a phase-sensitive demodulator (165), which is connected to the output (64) of the charge amplifier (62).

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"Apparatus for capacitive strain measurement"

The invention relates to an apparatus for measurement of strains or stresses, in particular to a biaxial capacitive strain gauge.

It is normally desirable to determine the loads and forces which are acting on various elements of a structure in

order to ensure that these elements are designed in a suitable manner to allow them to withstand the loads that occur on them, with a certain safety margin. While the stress forces in simple structures can easily be calculated if the loads are known, these calculations are unreasonably complex for complicated structures and/or unknown loads, and in many cases the solution is virtually impossible. In many application fields, it is therefore desirable to determine the forces empirically. In general, the forces are not accessible by direct measurement. In fact, the strain or deformation of the material, which is directly functionally related to the force acting, is measured using strain gauges or stress gauges.

A strain gauge or strain measurement transducer is an apparatus which exhibits a change in an electrical variable as a function of the stress on or the deformation of the material. The most widely used type is the resistance strain gauge, comprising a wire whose electrical resistance changes when it is subject to strain. This wire in a resistance strain gauge is attached to the surface of the material in which a stress is intended to be measured, such that the stress or strain which occurs causes a corresponding change in the resistance. A suitable electronic circuit, which is normally in the form of a Wheatstone bridge, is used to detect and to

measure the change in the resistance, and thus the strain.

Unfortunately, wires which have the desired characteristics for use in resistance strain gauges are in general also subject to changes in resistance as a function of temperature changes. For short time periods, these changes can be compensated for by means of a temperature compensation circuit. However, relatively long-lasting relatively high temperatures can lead to changes in the resistance which result from phenomena known by the expression "thermal ageing". These resistance changes can in general not be compensated for.

Another type of strain gauge or strain measurement transducer uses the change in a capacitor capacitance as a function of the strain or stress as a measurement variable. Previous capacitive strain gauges have been designed in such a manner that the operative elements of the device are subjected to the load. In these capacitive strain gauges and in resistance strain gauges in which the electrical resistance is subjected to the influencing forces in a similar manner, the electrical characteristics of the measurement apparatus change gradually when a load is acting for a relatively long time, as a consequence of permanent deformation of the loaded elements.

These phenomena are generally referred to as "creeping". As a result of creeping and thermal ageing, strain gauges are in general unstable when they are used over lengthy time periods and in particular at high temperatures.

Strain gauges are single-axis devices, that is to say they react only to dimension changes in a single direction. In order to allow the forces to be determined accurately at a point, it is, however, necessary to measure the stress or strain in at least two directions, from which it is possible to determine the true amplitude and direction of the stress. For this purpose, two or more strain gauges can be fitted close to one another, and with a specific angular position with respect to one another, on the surface to be investigated. This proximity is imprecise if the actually measured stresses do not occur at exactly the same point. In general, it is therefore preferable to use strain gauges which can be placed in layers one above the other, in order in this way to create a multiple-axis strain gauge. This can respond to stresses acting in different directions and which are registered essentially at one and the same point on the material surface to be tested.

The invention is based on the object of specifying a

capacitive strain gauge which has better long-term stability and is considerably less susceptible to thermal ageing and creeping. Furthermore, the capacitive strain gauge should be designed such that it is suitable for production of a multiple-axis capacitive strain gauge and operates reliably and accurately, with a simple design.

According to one preferred embodiment of the invention, it is proposed that these objects be achieved by a two-axis capacitive strain gauge having a laminar layer structure which defines two single-axis capacitive strain gauges with measurement directions located orthogonally with respect to one another. Each capacitive strain gauge has active capacitor plates, which are energized by means of an oscillator, and a capacitor measurement plate which is arranged at a distance from the capacitor plates that have been energized, and parallel to them. A shutter mechanism in the form of two shutter plates provided with apertures is arranged between the active capacitor plates and the capacitor measurement plates. The end sections of the shutter plates which are provided with apertures project out of the layer structure and are connected to the surface in which a stress or strain is intended to be measured. A stress leads to a relative movement between the shutter plates, which in turn results in a change in the

capacitor coupling, which takes place through the apertures, between the capacitor measurement plate and the active capacitor plates.

This capacitance difference is thus functionally related to the stress to be measured, and is registered and measured by a suitable electronic apparatus. In one particular embodiment, the active capacitor plates of each strain gauge are energized by two signals which have the same amplitude but have been phase-shifted through 180° with respect to one another. The shutter mechanism which is formed by the shutter plates results, because of the stress occurring in the material, in a decrease in the capacitance between one active capacitor plate and the capacitor measurement plate, and at the same in an increase in the capacitance between the other active capacitor plate and the capacitor measurement plate. The resultant change in the signal levels is recorded by a phase-sensitive demodulator, which produces an analogue signal proportional to the voltage.

Since the shutter plates of the capacitive strain gauge which form the shutter mechanism are, according to the present invention, not subject to any stress forces, this essentially precludes the phenomenon of creeping. Furthermore, all of the

capacitor plates are held such that they are firmly associated with one another in order in this way to reduce to a minimum the phenomena of thermal ageing and creeping. This results in a capacitive strain gauge with better long-term stability. The electronic apparatus which is used for the two-axis capacitive strain gauge according to the invention is relatively uninfluenced by amplifier drift or interference signals. In particular, the outputs of the strain gauge can be kept at a virtual earth potential by the use of a suitable negative feedback loop in conjunction with the amplifiers, which are connected to the outputs of the strain gauge. If the capacitances between the active capacitor plates and the capacitor measurement plate are not in equilibrium, the output of the amplifier thus supplies the necessary charge via the feedback loop in order to change the input to the virtual earth potential. If the output lines of the strain gauge are at earth potential, there is no capacitive coupling between these lines and earth. An earthed screened cable can thus be used in order to screen the lines against differential signals. The wires from the two capacitor measurement plates of the two-axis strain gauge can be routed in the same screen without any "crosstalk" taking place. The cables may be long and may be fitted with a surrounding winding without this resulting in any disadvantageous effects.

Further features and advantages will become evident from the following description, in which the invention will be explained with reference to one exemplary embodiment and in conjunction with the attached drawings, in which:

Figure 1 shows a partially cutaway perspective view of a two-axis capacitive strain gauge according to one preferred embodiment of the present invention,

Figure 2 shows a cross section through the apparatus illustrated in Figure 1,

Figures 3a and 3b show plan views of the active capacitor plates of the apparatus illustrated in Figure 1,

Figure 4 shows a partially cutaway plan view of the shutter plates, which form the shutter mechanism, in the apparatus illustrated in Figure 1, and

Figure 5 shows a schematic diagram of the two-axis capacitive strain gauge according to the invention with the associated electronic circuit.

Figures 1 and 2 show a two-axis capacitive strain gauge, which is annotated in general with A, according to one preferred embodiment of the invention. The strain gauge A has three mounting boards or laminates 10, 12 and 14, which are arranged in layers one on top of the other, with two laminates 10, 12 and 12, 14 in each case bounding a gap between them. A first single-axis capacitive strain gauge 16, which responds to a stress in a first direction or on a first axis, is formed in the gap between the surfaces of the laminates 10 and 12 which are adjacent to one another and are arranged at a distance from one another. A second strain gauge 16′ is formed in the same way in the gap between the mutually adjacent surfaces of the laminates 12 and 14 which are arranged at a distance from one another. The second strain gauge 16′ responds to a stress in a second direction or on a second axis, which is at right angles to the first axis

According to the preferred embodiment of the invention, the design of the second strain gauge 16′ is essentially identical to that of the first strain gauge 16, but is offset through 90° with respect to it in order in this way to align the measurement axes of the strain gauges 16 and 16′ orthogonally to one another. Only the first strain gauge 16 will therefore be described in detail, with this description

also being applicable to the second strain gauge 16′. In order to assist understanding, the reference numbers used in conjunction with the first strain gauge 16′ have also been used in the drawings for corresponding elements of the second strain gauge 16′, but with the addition of a prime symbol. This means that the elements 22, 24 etc. of the first strain gauge 16 correspond to the elements 22′, 24′ etc. of the second strain gauge 16′.

The strain gauge 16 has two active capacitor plates 22 and 24, which are arranged on the surface of the laminate 12 pointing towards the interior of the gap. The capacitor plates 22 and 24 are referred to as active capacitor plates, since they are energized by signals from the electronic device which is used in conjunction with the strain gauge. As can be seen in Figure 3a, the active capacitor plates 22 and 24 lie on one plane and are each formed with a row of elongated projections or fingers, which are parallel to one another and whose bases are connected to one another. The fingers of the active capacitor plates 22 and 24 engage in one another in such a manner that the fingers of the active capacitor plates 22 and 24 are located in a row, parallel to one another, in an alternating sequence. As will become evident in even more detail in the following text, the fingers of the active

capacitor plates 22 and 24 run essentially at right angles to the stress measurement axis of the strain gauge 16. It can thus be seen from Figure 3b, in which the active capacitor plates 22′ and 24′ of the second strain gauge 16′ are illustrated, that the capacitive plates 22′ and 24′ are rotated through 90° relative to the capacitor plates 22 and 24, so that the stress measurement axis of the strain gauge 16′ runs at right angles to the stress measurement axis of the strain gauge 16.

A coating composed of a dielectric material covers the capacitor plates 22 and 24. The dielectric coating 26 is used for insulation of the active capacitor plates 22 and 24 from the other elements of the strain gauge 16. One corner of the capacitor plates 22 and 24 is in each case not insulated, so that electrical lines 38 and 40 can be attached to the corresponding capacitor plates 22 and 24, with this normally being done by spot welding.

A capacitor measurement plate 28 is arranged on the inner surface of the laminate 10 pointing towards the gap interior. The capacitor measurement plate 28 is in this manner held parallel to the active capacitor plates 22 and 24, and at a distance from them. The capacitor measurement plate 28 in

general has a rectangular shape, corresponding to the area which is enclosed by the fingers of the capacitor plates 22 and 24. The capacitor measurement plate 28 has this name because it is connected to a suitable electronic apparatus for measurement of the change in the capacitance difference between the active plates 22 and 24. An electrical line 36 is thus attached to the capacitor measurement plate 28, to be precise preferably by spot welding to one corner of the capacitor measurement plate 28. The surface of the capacitor measurement plate 28 is covered by a dielectric layer 30, similar to the dielectric coating 26 which covers the capacitor plates 22 and 24, in order to isolate the capacitor measurement plate 28 from the other elements of the strain gauge 16.

As can be seen from Figures 2 and 4, a shutter mechanism in the form of shutter plates 32 and 34 provided with apertures is arranged between the active capacitor plates 22 and 24 and the capacitor measurement plate 28. The shutter plates 32 and 34 are mounted in the gap defined between the laminates 10 and 12, such that they can be moved along the stress measurement axis of the strain gauge 16. The shutter plates 32 and 34 extend on opposite sides beyond the laminates 10 and 12, so that they can be connected to the surface in

which a stress or strain is intended to be measured. Spacing elements 33 and 35, respectively, are attached to the outer ends of the shutter plates 32 and 34 for this purpose. The thickness of the spacing elements 33 and 35 corresponds to the distance between the shutter plates 32 and 34 and the surface in which a deformation or strain is intended to be measured. Compression or expansion of the surface in which a stress is intended to be measured thus leads to a movement of the shutter plates 32 and 34 relative to one another. This movement is used to produce a capacitance difference between the active capacitor plates 22 and 24 and the capacitor measurement plate 28.

As can be seen in Figure 4, the shutter plates 32 and 34 each have a plurality of rectangular apertures, which are annotated 32a and 34a. The apertures 32a and 34a are aligned parallel with the fingers of the active capacitor plates 22 and 24. When the shutter plates 32 and 34 are located one above the other, the apertures 32a and 34a are offset with respect to one another and thus form a large number of elongated rectangular aperture slots which are open through the plates 32 and 34. To be more precise, each of the apertures 32a is centred with respect to two adjacent apertures 34a such that two capacitor gaps C1 and C2 are

formed which are open through the mutually overlapping sections of the apertures 32a and 34a. The number of capacitor gaps C1 and C2 is thus twice as great as the number of apertures 32a and 34a in the respective shutter plates 32 and 34.

This results in the formation of an alternating row of capacitor gaps C1 and C2, which differ from one another in such a way that their dimensions vary in an opposite manner when the shutter plates 32 and 34 are moved relative to one another. An inward movement of the shutter plates 32 and 34 thus results in a reduction in the capacitor gap C1, while the capacitor gap C2 is at the same time enlarged. The capacitor gap C1 is thus arranged close to the fingers of the capacitor plate 22 in the strain gauge, while the capacitor plate C2 is in contrast arranged close to the fingers of the capacitor plate 24. In a corresponding manner, an inward movement of the shutter plates 32 and 34 leads to a decrease in the capacitance between the capacitor plate 22 and the capacitor measurement plate 28, while the capacitance between the capacitor plate 24 and the capacitor measurement plate 28 is at the same time increased. In a similar manner, an outward movement of the shutter plates 32 and 34 leads to an increase in the capacitance between the capacitor plate 22 and the

capacitor measurement plate 28, while in contrast the capacitance between the capacitor plate 24 and the capacitor measurement plate 28 is at the same time decreased.

The principle of operation of the strain gauge is thus that the actual capacitance between the capacitor measurement plate 28 and the respective capacitor plate 22 or 24 is in each case governed by the relative position of the shutter plates. The actual capacitance between the capacitor plate 22 and the capacitor measurement plate 28 is proportional to the area of the capacitor gap C1. If a capacitor gap C1 is now considered, the capacitance between the capacitor plate 22 and the capacitor measurement plate 28 is now given by the following expression, ignoring edge effects:

$$C_1 = k \cdot x_1 \cdot 1_c$$

In this case, k is a proportionality constant whose value depends on the plate separation and the dielectric constant. In a corresponding manner, the capacitance between the capacitor plate 24 and the capacitor measurement plate 28 is:

$$C_2 = k \cdot x_2 \cdot 1_c$$

The capacitance difference is thus given by:

$$C_d = C_1 - C_2 = k \cdot 1_c \cdot (x_1 - x_2)$$

otherwise

$$x_c = x_1 + x_a + x_2$$

it follows that

$$c_d = k \cdot 1_c \cdot \ (2x_1 + x_a - x_c).$$

In this case, 1_c is the length of a slot 34a, x_a is the width of a web between two mutually adjacent apertures 32a, x_c is the width of an aperture 34a, x_1 is the width of a capacitor gap c_1 and x_2 is the width of a capacitor gap C_2.

The capacitance difference is thus a function of the relative position of the shutter plates 32 and 34 and of the dimensions of the apertures 32a and 34a, and the constant k.

The response accuracy of the strain gauge to relative movement of the shutter plates 32 and 34 is expressed by:

$$K_x = N\frac{dCd}{dx_1} = 2N \cdot k \cdot 1_c$$

In this case, N indicates the number of apertures 32a and 34a, only one of which will be considered in the following analysis.

As has already been mentioned briefly above, the strain gauge 16', which is aligned orthogonally with respect to the strain gauge 16, is essentially identical to the strain gauge 6, in terms of design and method of operation. The aim, of course, is for the strain gauge 16' to respond to deformation in an orthogonal direction with respect to the stress measurement axis of the strain gauge 16, so that all of the elements of the strain gauge 16' are rotated through 90° with respect to the corresponding elements of the strain gauge 16. Apart from this, the design and method of operation correspond to the above description.

The two-axis capacitive strain gauge A according to the preferred embodiment of the present invention has safety devices against interference phenomena and disturbance signals. In particular, a pair of screening plates 20 are provided on the outer surfaces of the laminates 10 and 14 and

are earthed to the screen of the strain gauge A. The shutter plates 32, 34, 32′ and 34′ are earthed in the same way. If the strain gauge A is mounted on an earthed metal surface, the respective plates can be earthed by touching the surface on which deformation is intended to be measured. Otherwise, if the strain gauge A is intended to be used on an insulated or unearthed surface, earthing lines should be provided to the shutter plates. In addition to the screening by the screening plates 20 and the shutter plates 32 and 34, additional isolation is provided against interference phenomena and disturbance signals by the nature of the electronic device which is used together with the strain gauge A and will now be described in the following text.

The electronic device used together with the strain gauge A will now be described in more detail with reference to Figure 5. Since the strain gauges 16 and 16′ are essentially independent of one another, a double-channel embodiment of the electronic device is provided for the two strain gauges 16 and 16′, with the exception that a single signal transmitter can be used to energize the strain gauges. The strain gauge 16 is energized by an oscillator 60, which has a very low output impedance, by means of two carrier signals which are phase-shifted through 180° with respect to one another and have the

same amplitude. The line 38 thus connects a first phase output of the oscillator 60 to the capacitor plate 22. In a corresponding manner, the line 40 connects the output for the second phase (phase-shifted through 180° with respect to the first phase) of the oscillator 60 to the capacitor plate 24. Since a single oscillator 60 can be used to energize both strain gauges 16 and 16′, the capacitor plates 22 and 22′ are connected to the line 38 parallel to one another, and the capacitor plates 24 and 24′ are connected to the line 40 parallel to one another.

The strain gauge 16 can be compared with two variable capacitors which are coupled to one another in such a manner that their capacitances vary inversely with respect to one another, as is illustrated in Figure 5. The outputs of the two capacitors coincide in the capacitor plate 28, which is connected to an output line 36. Without any stress or deformation being forced, the capacitor gaps C1 and C2 which are formed by the shutter plates 32 and 34 are essentially of identical magnitude, so that identical amplitudes of the first oscillator signal, which is in phase, and of the second or phase-shifted oscillator signal are coupled to the capacitor measurement plate 28. The signals of the same amplitude cancel one another out, so that the output signal from the strain

gauge 16 is equal to zero when no deformation is present. Compression of the surface on which deformation is intended to be measured leads to a constriction of the capacitor gap C1 and at the same time to widening of the capacitor slot C2. This results in a reduction in the amplitude of the in-phase oscillator signal which is coupled through the capacitor slots C1 to the capacitor measurement plate 28, and at the same time in an increase in the amplitude of the phase-shifted oscillator signal which is coupled through the capacitor gap C2 to the capacitor measurement plate 28. Compression deformation thus causes a phase-shifted output signal on the output line 36. In a corresponding manner, expansion deformation causes an increase in the capacitor gap C1 and a reduction in the capacitor gap C2, which leads to an in-phase output signal on the output line 36.

The output line 36 is connected to the input of a charge amplifier 62, for amplification of the signal, in order to record and to measure the signal which appears on the output line 36. The charge amplifier 62 has a feedback capacitor 66 which couples the output 64 with the input to the output line 36. The negative feedback which is produced by the feedback capacitor 66 is used to keep the output line 36 at a virtual earth potential. Thus, in particular, the appearance of a

signal on the output line 36 results in a sufficient amount of charge flowing back to the feedback capacitor 66 in order to change the output line 36 to a virtual earth potential. Holding the output line 36 at a virtual earth potential further reduces the sensitivity of the arrangement to any change in the cable capacitance and to disturbance signals. Furthermore, the output line 36 can be carried in a simple earthed screening cable, without any disadvantageous effects. The output line 36′ which is connected to the orthogonally aligned strain gauge 16′, can run in the same screening cable, parallel to the line 36.

The output 64 of the charge amplifier 62 can be connected to a phase-sensitive detector 165 in order to produce a simple direct-current signal, which is proportional to the capacitance difference and thus proportional to the deformation. The detector 165, for example a demodulator, is used to eliminate alternating-current carrier signals, although these receive real amplitude information. The demodulator is preferably phase-sensitive in order to make it possible to distinguish between compressive and extensive deformations, which produce output signals of opposite phase, as in the above description.

A large number of materials may be used for construction of a two-axis capacitive strain gauge A corresponding to the present invention. However, it has been found that certain materials are particularly suitable for use of the strain gauge in high-temperature environments. For example, the laminates 10, 12 and 14 are preferably produced from aluminium, while the capacitor plates 22, 24, 22′, 24′, the capacitor measurement plates 28 and 28′ and the screening plates 20 are preferably composed of platinum printed on to the surface of the laminates 10, 12 and 14. The shutter plates 32, 34, 32′, 34′ are preferably produced from stainless steel. The apertures 32a, 34a, 32a′ and 34a′ are normally produced by means of a conventional photographic etching process. The dielectric insulating layers 26, 30, 26′ and 30′ may be formed essentially from a thin ceramic film. The lines 36, 36′, 38 and 40 may be produced from nickel. All of these materials have been chosen on the basis of their resistance to oxidation at high temperatures, so that the preferred embodiment of the present invention is particularly suitable for use in high-temperature environments. For example a design according to the invention has been used successfully over long time periods at temperatures of approximately 593.6°C (1100°F). Other materials which are suitable for a given environment and have the required electrical characteristics can also, of

course, be used.

The major proportion of the capacitance which is developed between the capacitor plates on the one hand and the capacitor measurement plate on the other hand is a consequence of the air gap between the plates. The strain gauge A may, however, also operate with any non-conductive liquid in the gap between these plates, provided that this liquid does not physically impede the movement of the shutter plates 32, 34, 32′ and 34′.

The strain gauge A according to the present invention may be constructed in any desired size. One suitable embodiment has a stack of laminates of an essentially square shape with an edge length of 12.7 mm and a height of 2.31 mm. One preferred nominal thickness for all of the plates and layers with the exception of the laminates 10, 12 and 14 is 0.0254 mm. It has been found that a total of four apertures 32a or 34a in the shutter plates 32 or 34 is suitable for a design such as this. In a corresponding manner, in this embodiment, the capacitor plates 22 and 24 each have four elongated projections or fingers, with four capacitor gaps C1 being provided for coupling of the capacitor plate 22 to the capacitor measurement plate 28, and four capacitor gaps C2

being provided for coupling of the capacitor plate 24 to the capacitor measurement plate 28. Other dimensions and numbers of apertures and gaps may, of course, also be used depending on the desired size and shape.